"Natural Neighbor" Meshless Method for Modeling Extreme Deformations and Failure

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The objective of this work is to develop a fully Lagrangian analysis approach based on "natural neighbor" discretization techniques to model extreme deformation and failure for analyses such as earth penetration and dam failure. The standard finite element approaches often do not work in these applications because of "mesh tangling" (Fig. 1). Lagrangian methods allow the tracking of particles and free surfaces, which makes handling of sophisticated material models and effects due to debris and fragmentation much more straightforward and natural as compared to Eulerian and arbitrary-Lagrangian-Eulerian (ALE)-type methods. On the other hand, the standard meshless particle methods have other pathologies such as instabilities and insufficient treatment of boundaries and inefficiencies. The application of novel shape functions based on natural neighbors has been successfully used in this work to overcome many of these pathologies.

Project Goals

The goal of this work is to fix many of the inherent problems associated with meshless methods. This involves the development of several neighbor-based approximation methods, stable time-step calculations, and techniques for improving efficiency. A number of refereed journal articles resulted from this work and the methods are currently implemented and available in Laboratory codes. Verification and validation and material modeling have also been a key component of our effort.

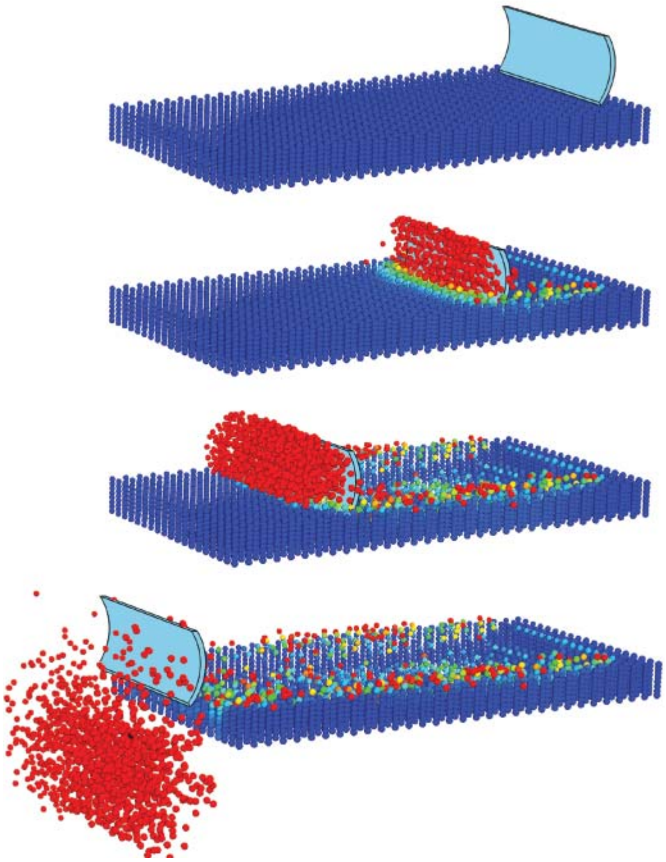


Figure 1. DYNA3D particle simulation of earth moving problem. This type of analysis would not be feasible with finite elements due to mesh tangling.

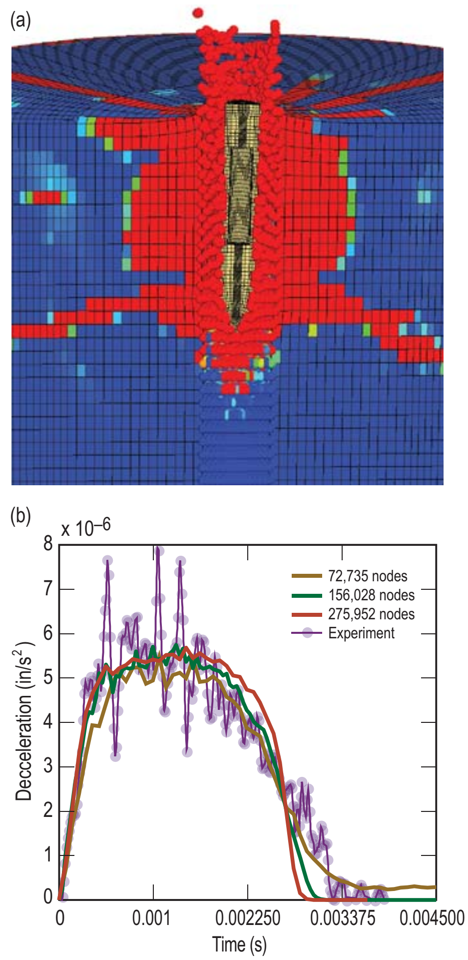
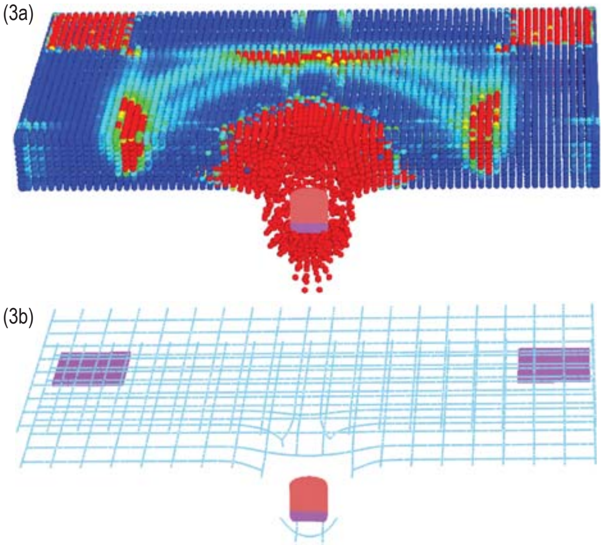


Figure 2. (a) DYNA3D simulation of concrete penetration (tensile damage shown in red); (b) comparison of simulation results to experimental results from Sandia National Laboratories. Three different nodal discretizations were used in the simulation and all compare well to the Sandia test results.



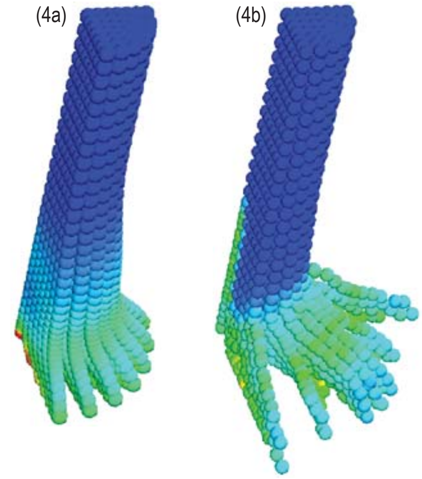


Figure 3. (a) DYNA3D simulation of penetration of reinforced concrete (tensile damage shown in red); (b) rebar (shown alone) attached to particles in the simulation (eventually fails upon exit). Simulations compare well to data in the literature.

Figure 4. (a) View of Taylor bar from new particle method simulation. An evolving elliptical kernel was used to maintain proper particle connectivity. (b) Results from classical particle methods (*e.g.* Smoothed Particle Hydrodynamics) where "toeing" results. This effect is often attributed to a tensile instability.

Relevance to LLNL Mission

A number of high profile analysis areas will benefit from this work. High rate penetration dynamics is identified as a challenge area in engineering and validation work in this area (Fig. 2) has already been done using the new approaches with the LLNL code DYNA3D. Homeland Security applications are important to the LLNL mission and validation has begun looking at the effects of penetrators on reinforced concrete walls (Fig. 3).

FY2007 Accomplishments and Results

Our FY2005 implementation used a natural neighbor scheme that required the computation of a Voronoi diagram at each step of an analysis. In FY2006, we proposed a simplified scheme where natural neighbors were used to form elliptical kernel functions in a moving least squares (MLS) approach for computing shape functions.

In FY2007 this method was extended to the treatment of large deformation problems by applying the appropriate evolution scheme for the elliptical kernels (Fig. 4). In addition, a maximum entropy (MAXENT) method was applied as an alternative to the MLS approach to better treat essential boundary conditions. Given an elliptical kernel function ω_i at node i, MAXENT shape functions ϕ_i are chosen by minimizing the informational entropy function f in (1), subject to the partition of unity and linear exactness constraints in (2).

$$f(x;\phi) = -\sum_{i=1}^{n} \phi_i(x) \ln\left(\frac{\phi_i(x)}{w_i(x)}\right) \quad (1)$$

$$\sum_{i=1}^{n} \phi_i(x) = 1,$$
$$\sum_{i=1}^{n} \phi_i(x)(x^i - x) = 0, \quad (2)$$

Finally, a new method for handling principal stress damage with plasticity was implemented in the concrete model used in the penetrator analysis shown in Figs. 2 and 3. The remainder of our work was in the area of verification and validation as demonstrated in Figs. 2 through 4.

Related References

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4. Chen, J. S., W. Hu, and M. A. Puso, "Strain Smoothing for Stabilization and Regularization of Galerkin Meshfree Methods," *Third International Workshop on Meshfree Methods, Proceedings of Third International Workshop on Meshfree Methods, Meshfree Methods for Partial Differential Equations III, volume 57 of Lecture Notes in Computational Science and Engineering*, Bonn, Germany, September 12 – 15, 2005.
5. Chen, J. S., W. Hu, and M. A. Puso, "Orbital HP-Clouds and Higher Order SCNI for Solving Schrodinger Equation in Quantum Mechanics," *International Journal for Numerical Methods in Engineering*, **67**, pp. 847-867, 2007.

FY2008 Proposed Work

Our goal of developing an accurate and efficient particle method has been met. Nonetheless, a number of research areas still exist. For example, initial particle placement has a large influence on the accuracy of the results. Continued work in the area of large deformation material modeling is also needed.